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MEMORANDUM REPORT ARCCB-MR-00006

CRITICAL COMMENTS ON REPORT TITLED "*GRAY LAYERS AND THE EROSION OF CHROMIUM PLATED GUN BORE SURFACES*" BY COTE AND RICKARD

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APRIL 2000

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 2000

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
CRITICAL COMMENTS ON REPORT TITLED "*GRAY LAYERS AND THE EROSION OF CHROMIUM PLATED GUN BORE SURFACES*" BY COTE AND RICKARD

5. FUNDING NUMBERS
PRON No. TU9B9F101ABJ

6. AUTHOR(S)
J.H. Underwood

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER
ARCCB-MR-00006

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In June 1999, Dr. Cote supplied a prepublication copy of his and Mr. Rickard's report, "*Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces*," and requested this author's comments. These comments are offered here.

14. SUBJECT TERMS
Erosion, Thermal Damage, Cannons, Chromium Plate

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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INTRODUCTION

In June 1999, Dr. Cote supplied a prepublication copy of his and Mr. Rickard's report, "*Gray Layers and the Erosion of Chromium Plated Gun Bore Surfaces,*" (ref 1) and requested this author's comments. These comments are offered here.

Erosion of gun bore surfaces is clearly one of the most critical topics facing ARDEC, so the authors should be complimented for undertaking this work. They apply both proven and novel metallography methods to samples from guns that were fired with recent, high-temperature rounds. Thus, their results deserve attention.

CAUSE OR CONSEQUENCE

The problem this author has with their report is with the main conclusion of the work, which is well stated in the authors' words from their Discussion section:

> *"...the present observations of the initiation and gradual progression of oxygen and sulfur attack into the steel do not support the suggestion that hydrogen cracking of the steel, after firing, initiates failure of the chromium."*

Cote and Rickard conclude that oxygen and sulfur attack of the steel is the cause of chromium loss and erosion in guns, and that hydrogen cracking is not involved. This author disagrees with this conclusion, and suggests that hydrogen cracking is the initial and critical cause of steel damage and subsequent chromium loss and erosion, whereas oxygen and sulfur attack occurs **after** hydrogen cracking as a consequence of that cracking. Simply stated, hydrogen cracking is the initial cause of chromium loss, and gray layer formation is a consequence of hydrogen cracking. Thus, gray layers could have at most a secondary effect on chromium loss and erosion in cannon tubes. A comparison of certain aspects of hydrogen cracking and gray layer formation—based on Figures 5 and 7a of the Cote and Rickard report and on prior ARDEC reports—is given below, to support the contention that hydrogen cracks are a cause and gray layers are a consequence.

COMPARISON OF HYDROGEN CRACKS AND GRAY LAYERS

Morphology of Cracks and Gray Layers

It is clear from Figures 5 and 7a (and supported by other Cote and Rickard photomicrographs) that gray layers are observed as, "*outlining many of the larger crack-like features,*" again using the authors' words. The obvious explanation for this configuration of a crack outlined by a gray layer is that the crack formed after the required number of firings and **then** opened in subsequent firings to admit propellant gases that formed the gray layer. So the cracks cause the initial damage in the steel beneath the chromium, and the gray layers are a consequence of the cracks. Further, based on recent work at Benet (refs 2,3) and a long progression of results from the literature, it is clear

that the cracks in Figures 5 and 7a have the characteristic features of hydrogen cracks as observed in cannons and other components.

Time and Temperature Requirements

Vigilante and coworkers (ref 3) and others in the literature have shown that hydrogen cracks can grow very quickly in gun steel at room temperature. Also, there is clear evidence (ref 2) that cannon firing provides the sustained tensile stress and hydrogen environment required for hydrogen cracking. Thus, it is quite plausible that the cracks shown in Figures 5 and 7a are hydrogen cracks.

In contrast, there seems to be considerable question that the cracks shown in Figures 5 and 7a could have been formed by "*the gradual progression of oxygen and sulfur attack into the steel.*" It is doubtful that there could have been enough time at temperature. It is known that the high temperatures required for sulfur attack have only a few milliseconds duration during a cannon firing cycle, whereas an example of sufidation cracking from the literature (ref 4) led to failure only after 8500 hours at 1700°F. So the growth of a long slender gray layer along a line to somehow cause the crack-like appearance in Figures 5 and 7a does not seem very plausible. The very shape of the "*crack-like features*" in Figures 5 and 7a support this. The length extending into the steel is clearly very much greater than the width, and this is consistent with a hydrogen crack growing in response to a **sustained** tensile stress, followed by much slower growth of gray layers in response to a **brief** high-temperature exposure during subsequent firing cycles.

REFERENCES

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2. Underwood, J.H., Parker, A.P., Cote, P.J., and Sopok, S., "Compressive Thermal Yielding Leading to Hydrogen Cracking in a Fired Cannon," *Journal of Pressure Vessel Technology*, 1999.

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